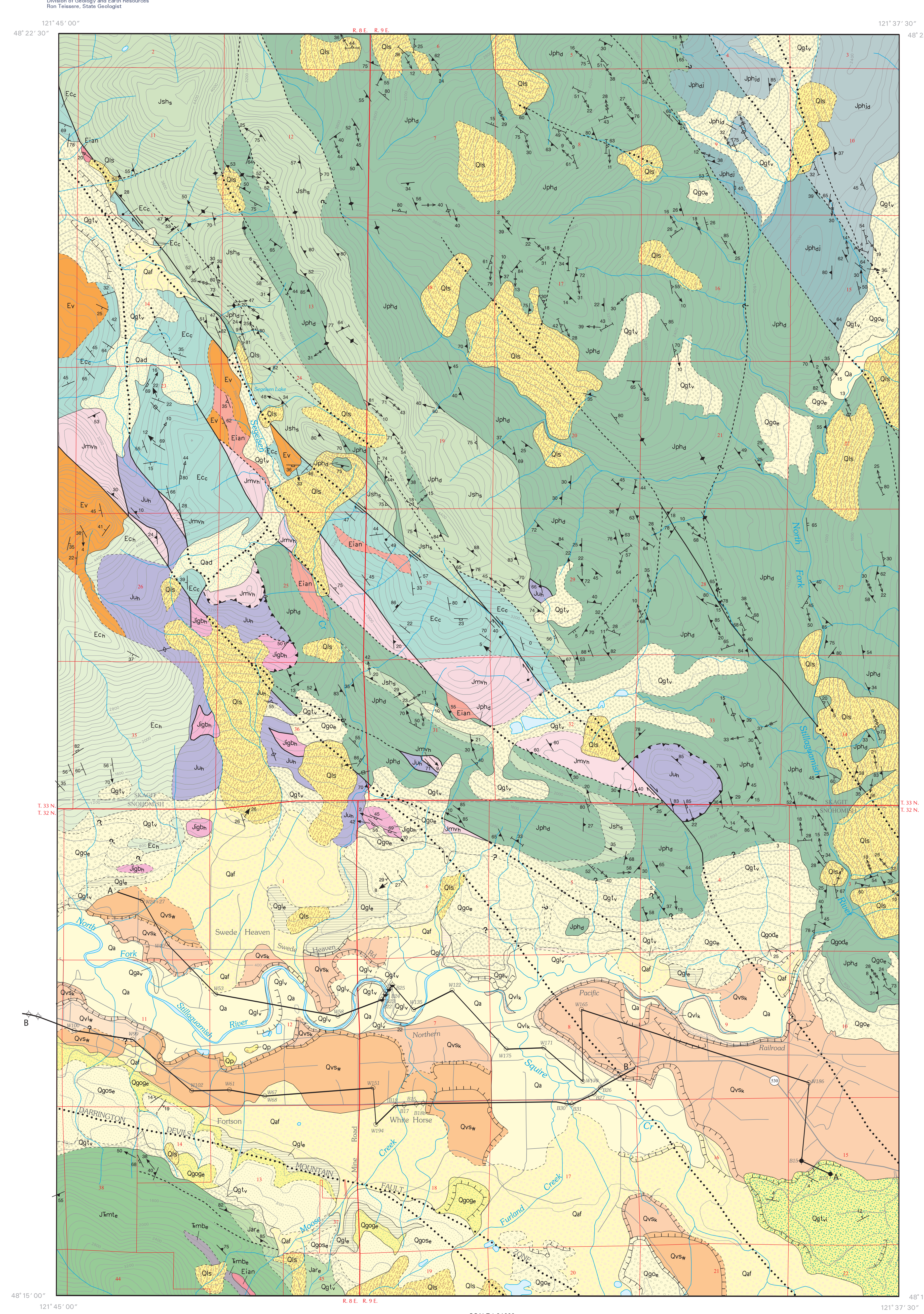
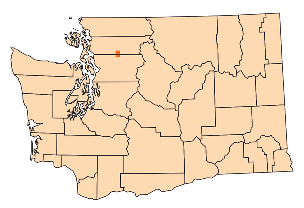
WASHINGTON STATE DEPARTMENT OF Natural Resources
Doug Sutherland - Commissioner of Public Lands
Division of Geology and Earth Resources
Ron Teissere, State Geologist

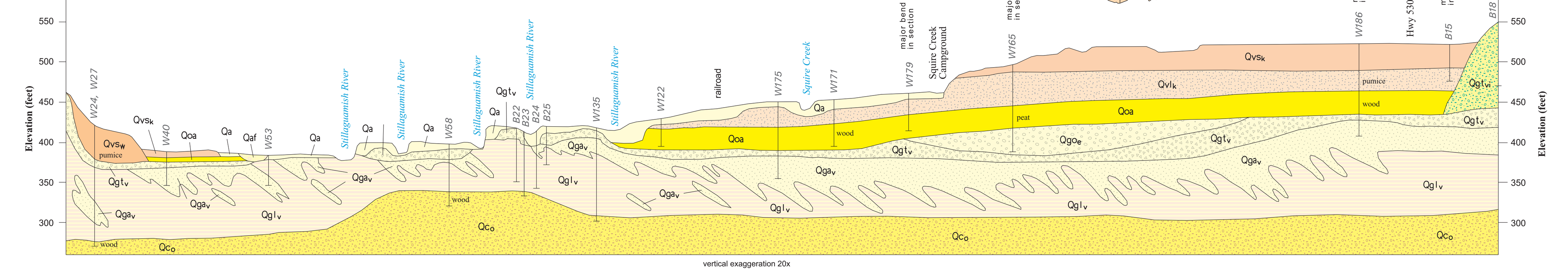


Lambert Conformal projection
1927 North American Datum
Washington coordinate system, south zone
Base map information from the Washington Department of Natural Resources, Geographic Information System 1997
Digital Cartography by Anne C. Heinitz and Donald T. McKay, Jr.

SCALE 1:24000

contour interval 100 feet

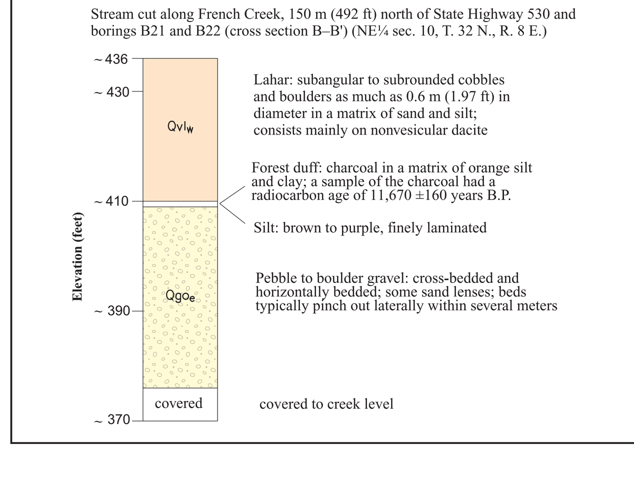


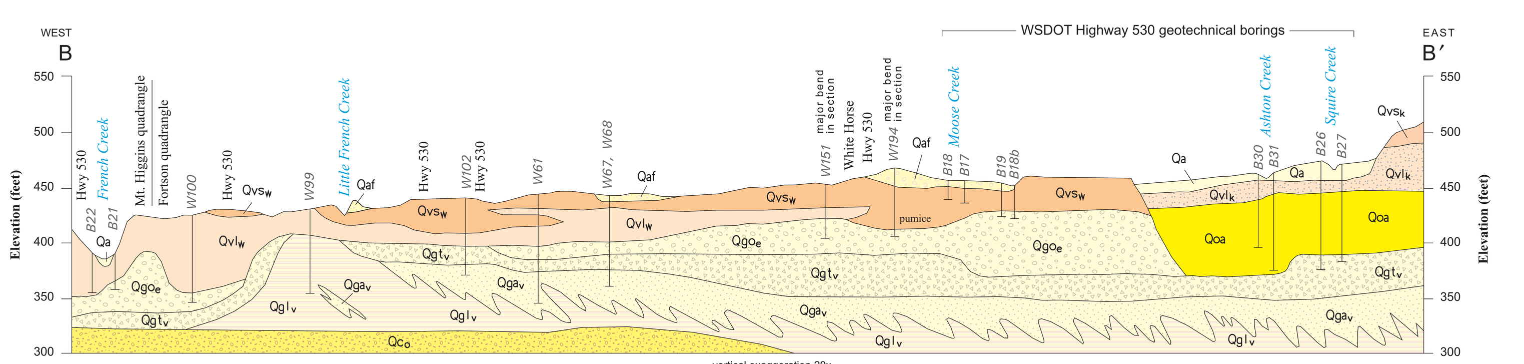


vertical exaggeration 20x

Measured section 6 of Beget (1982)

Stream cut along French Creek, 150 m (492 ft) north of State Highway 530 and borings B21 and B22 (cross section B–B′) (NE¼ sec. 10, T. 32 N., R. 8 E.)





vertical exaggeration 20x

Note that the cross sections are not straight lines but segments that connect geotechnical or water well boring logs and thus contain multiple bends. Most segments traverse areas of good to excellent geologic mapping control. The numbers above the wells or borings provide our assigned identification number; water wells begin with "W" and geotechnical borings begin with "B".

Geologic Symbols

Contact—Dashed where inferred; dotted where concealed; queried where location uncertain

Fault, unknown offset—Dashed where inferred; dotted where concealed; queried where location uncertain

Normal fault—Bar and bell on downthrown side; dashed where inferred

Normal right-lateral strike-slip fault—Bar and bell on downthrown side; half arrows indicate relative apparent strike-slip motion

Right-lateral strike-slip fault—Half arrows indicate relative apparent strike-slip motion; dashed where inferred

Thrust fault—Sawteeth on upper plate; dashed where inferred; dotted where concealed

Latest Pleistocene to Holocene fluvial terrace—Hachures on scarp side

Strike and dip of bedding (may be combined with other symbols)

inclined (glacial and volcanic deposits only)

inclined—indicates foreset bedding (glacial and volcanic deposits only)

inclined

inclined—parallel to tectonic foliation

Trend and plunge of fold axes (may be combined with other symbols)

Minor F1 (first-generation) fold axis; arrow indicates the direction of plunge

Minor F2 (second-generation) fold axis and (or) crenulation lineation; arrow indicates direction of plunge

Minor F3 (third-generation) fold axis and (or) crenulation lineation; arrow indicates direction of plunge

Minor F2 M-shaped fold axis and (or) crenulation lineation; arrow indicates direction of plunge

Minor F2 Z-shaped fold axis and (or) crenulation lineation; arrow indicates direction of plunge

Minor F2 S-shaped fold axis and (or) crenulation lineation; arrow indicates direction of plunge

Strike and dip of tectonic foliation (may be combined with other symbols)

Penetrative tectonic foliation (undifferentiated); generally crystalloblastic S1 (first-generation) cleavage in the Shuksan Suite; generally syn- to late-metamorphic protomylonitic to mylonitic in Helena–Haystack mélange meta-igneous rocks

inclined

vertical

inclined—may locally represent S2 or S3 foliation

vertical—may locally represent S2 or S3 foliation

Strongly developed semi-penetrative to locally penetrative S2 (second-generation) axial plane foliation or F2 axial plane

inclined

F2 axial plane (no S2 foliation)

inclined

vertical

Strongly developed semi-penetrative to locally penetrative S3 (third-generation) axial plane foliation or F3 axial plane

inclined

Strike and dip of fractures and joints (may be combined with other symbols)

Joint, undifferentiated

inclined

Subsidiary minor fault or slickensided fracture plane

inclined

vertical

Subsidiary fault (commonly with gouge zone)

inclined

Trend and plunge of tectonic lineations

Lineation, undifferentiated (mostly stretching lineations and crenulation lineations; rarely pencil lineations, slickenlines, or boudins); arrow indicates direction of plunge

inclined

Stretching lineation; arrow indicates direction of plunge

inclined

Trend and plunge of current flow direction indicators (flutes, pebble imbrications, etc.)

inclined

Well and Borehole Symbols

Water well

Washington State Department of Transportation geotechnical borehole

GeoEngineers, Inc., geotechnical borehole

Snohomish County geotechnical borehole

Description of Map Units

Field mapping of the Fortson 7.5-minute quadrangle was completed during the summers of 2001 and 2002. Field observations were supplemented by whole-rock and clast geochemical analyses, pumice and ash (glass) microprobe analyses, radiocarbon dating, petrographic (thin section) analyses of bedrock, clasts, and mounted Quaternary sands, and subsurface analyses using water wells and geotechnical borings. A copy the sample site map can be obtained by writing to Joe Dragovich at the Washington Division of Geology and Earth Resources, PO Box 47007, Olympia, WA 98504-7007, joe.dragovich@wadnr.gov. Alphanumeric codes following color descriptions refer to the Munsell rock color chart (Munsell Color, 1998) and are for dry samples.

QUATERNARY SEDIMENTARY AND VOLCANIC DEPOSITS

Holocene Nonglacial Deposits

Qa / Qp — **Alluvium, undivided (Holocene)**—Gravel, gravelly sand, sand, and cobbly gravel with rare boulders; gray; subrounded to rounded clasts; loose, well-stratified, and well-sorted; plane-bedded sands common; locally contains up to 30% reworked gray or reddish gray Glacier Peak dacite with boulder fraction locally greater than 50% dacite; locally rich in granitic and (or) phyllite clasts. Overbank deposits are mostly loose or soft to stiff, grayish brown to olive-gray stratified sand, fine sandy silt, silt, silty clay, and minor peat (unit Qp). Several radiocarbon ages from sticks in peat and organic sediments yield ages of less than 600 yr B.P. for Stillaguamish River alluvium.

Qoa — **Older alluvium (Holocene) (cross sections only)**—Sand, gravel, cobbly gravel, silt, clay, and peat locally with abundant wood and organic matter (downed trees, shrubs, paleosols, and swampy deposits) (cross sections A–A′, B–B′). Unit Qoa occurs below units Qvl_k and Qvs_k (mid-Holocene). The uppermost portion of unit Qoa commonly contains organic materials and is interpreted as a forest buried by Glacier Peak volcanic deposits (unit Qvl_k) during the mid-Holocene.

Qaf — **Alluvial fan deposits (Holocene)**—Diamicton; massive to weakly stratified with angular to rounded, locally derived clasts; mostly poorly sorted debris-flow or debris-torrent deposits, locally modified by fluvial processes. Alluvial fans mostly disconformably overlie glacial or Glacier Peak volcanic deposits and locally interfinger with alluvium (units Qa and Qoa).

Qls — **Landslide complexes (Holocene)**—Boulders, cobbles, and gravel in a soft sand, silt, and (or) clay matrix; mostly poorly sorted and unstratified with locally derived angular to rounded clasts. Includes deep-seated landslides such as slump-earthflows and a few of the most prominent debris slide and talus or rockfall deposits. Scarps and deposits are mapped together as unit Qls.

Holocene Glacial Deposits

Qad — **Alpine till (Holocene?)**—Dark olive gray gravelly clayey sand or sandy pebbly diamicton with clasts of andesite and basalt derived from unit Ev. Diamicton interpreted as a Holocene alpine glacial deposit but may be Vashon till with abundant locally derived clasts.

Late Pleistocene and Holocene Glacier Peak Volcanic and Sedimentary Deposits

We correlate the volcanic assemblages in the study area with the Kennedy Creek and White Chuck assemblages of Beget (1981, 1982) that inundated valleys during mid-Holocene and late Pleistocene eruptive episodes of Glacier Peak. These deposits are exposed as terraces with age increasing with elevation. For example, White Chuck assemblage terraces are typically up to 80 ft (24 m) above the modern flood plain and are higher than later volcanic assemblages. Glacier Peak dacite is homogeneous and contains plagioclase, hornblende, and hypersthene ± augite and (or) olivine phenocrysts and rare biotite; each assemblage appears to have a generally similar but distinctive dacite-clast trace-element geochemistry (Dragovich and others, 1999, 2000a,b,c,d; J. D. Dragovich, Wash. Divn. of Geology and Earth Resources, unpub. data).

Kennedy Creek Assemblage

The Kennedy Creek assemblage (KCA) originated from Glacier Peak and flowed down the Sauk and Stillaguamish River valleys about 5,100 to 5,400 yr B.P. (Beget, 1981, 1982; Dragovich and others, 1999, 2000a,b,c; J. D. Dragovich, Wash. Divn. of Geology and Earth Resources, unpub. data). The KCA forms a prominent 15 to 25 ft (5–8 m) high terrace. Stratigraphic relations as well as geochemical and petrographic data suggest that the assemblage resulted from inundation by lahar(s) that transformed into hyperconcentrated flood(s) downstream through interaction with river water. This transformation is similar to the mechanism envisioned by Pierson and Scott (1985) for similar Mount St. Helens deposits. Hyperconcentrated flood deposits thicken to the west in the Stillaguamish River drainage as a result of this transformation. Subsequent fluvial incision and channel migration locally reworked the top of the KCA. The KCA forms a flat divide between the Sauk and Stillaguamish Rivers (Dragovich and others, 2002a). Beget (1981) suggested that the divide formed during deposition of the latest Pleistocene White Chuck assemblage, diverting the Sauk River north to the Skagit River east of the study area. (White Chuck volcanic inundation occurred during the close of the last glaciation, when organic productivity was low and organic deposition was rare to nonexistent.) However, unit Qoa, which underlies the volcanic sediments of the divide (cross sections A–A′, B–B′), contains organic material at various stratigraphic levels, implying quiescent post-glacial deposition representing much of the early Holocene. Therefore, we associate formation of this divide with deposition of the mid-Holocene KCA rather than the White Chuck assemblage.

Qvs_k — **Volcanic sediments, undivided (Holocene)**—Hyperconcentrated flood deposits, lahars, and volcanic alluvium; medium- to coarse-grained sand and thick beds of gravelly sand and cobbly sandy gravel; loose; dacite-rich. Locally contains lahar beds of silty sandy gravel with few cobbles and boulders; these beds are similar to unit Qvl_k, but are too thin (0.5–2 m or 1.5–6 ft) to separate at map scale; some lahars occur within granular hyperconcentrated flow deposits (this study; J. D. Dragovich, Wash. Divn. of Geology and Earth Resources, unpub. data). Locally capped by reworked light brownish gray to light yellowish brown ash (10YR 6/2, 6/4, 7/1, 2.5YR 6/3) or ash with scattered lenses of pumice lapilli. Clasts include 70% to 98% light gray to gray (GLEY 1 5/N-7/N) dacite locally with scattered dark gray (GLEY 1 2.5/N-4/N) and altered pale red to dark reddish gray dacite (10YR 5/2, 10R 3/1, 7/2, 6/2-6/3); locally contains up to 50% pale yellow, very pale brown, light gray, white, or pinkish white pumice (GLEY 1 5/N-8/N, 2.5YR 8/1-8/2, 10YR 5/1, 7/2, 8/1-8/3) as lenses or scattered clasts. Locally contains cobble- to boulder-sized rip-up clasts of silt and (or) clay that were probably eroded from deposits mapped near Glacier Peak by Beget (1981) as sediments of volcanically dammed lakes. Nonlahar beds are typically nongraded to crudely graded and nonstratified; locally contains weak horizontal stratification, plane bedding, and cross bedding including rare antidunes. Stratigraphy and clast compositions indicate both fluvial and hyperconcentrated flood depositional mechanisms for the nonlaharic sediments. Reworked terrace-capping tephra probably represents one or more waning flood deposits. Locally divided into:

Qvl_k — **Non-cohesive lahar (Holocene)**—Silty sandy gravel to gravelly sand locally with cobbles and rare boulders up to 1 m (3 ft); compact; dacite-rich with clasts typically 1 to 2 cm (0.4–0.8 in.) but locally 10 to 30 cm (4–12 in.) in size. Very pale brown (10YR 7/3) lahar matrix consists mostly of reworked pyroclasts of fine to coarse ash with crystals of hornblende, hypersthene, plagioclase, quartz, and rare augite, with vitric fragments and fragments of dacite. Dacite clasts are angular to subangular, abundant (80–98% of clast component), and vesicular to locally non-vesicular; some frothy flow banding; mostly gray (GLEY 1 5/N-6N) with some scattered altered reddish gray dacite (2.5Y 6/2) and pale yellow, pale brown, and pink pumice (10YR 8/2, 10R 8/3). Unit also contains rare boulder-sized rip-up clasts of lacustrine clay and minor exotic clasts of granite, phyllite, and vein quartz. Nonstratified deposits with weak normal grading occur near the top of the deposit. Commonly contains dewatering and (or) gas-escape pipes; rarely contains crudely defined, meter-scale horizontal stratification defined by coarse-tail (gravel and cobble) grading; rarely contains flame structures, internal truncation surfaces, and very thin ash beds. Paleomagnetic analysis of dacite clasts (J. Ladd, Western Wash. Univ., written commun., 2002) suggests deposition as a hot lahar. Although base was not observed, deposit appears to be mostly laterally continuous and may be as thick as 15 m (49 ft) (cross sections A–A′, B–B′); overlain by volcanic sediments of unit Qvs_k (this study; J. D. Dragovich, Wash. Divn. of Geology and Earth Resources, unpub. data).

White Chuck Assemblage

The White Chuck assemblage resulted from Glacier Peak eruptions during Fraser deglaciation (~11,200–12,700 yr B.P.) (Beget, 1981, 1982; Porter, 1978; Foit and others, 1993). Deposits of the White Chuck assemblage commonly overlie dacite-poor recessional outwash of unit Qgo_e.

Qvs_w — **Volcanic sediments, undivided (late Pleistocene)**—Hyperconcentrated flood deposits, lahars, and volcanic alluvium; medium- to coarse-grained sand, sandy gravel, and cobbly sandy gravel; loose; dacite-rich. Lahars consist of poorly sorted, nonstratified gravelly silty sand and silty sandy gravel with some cobbles and scattered boulders up to 44 cm (17 in.). Volcanic alluvium and hyperconcentrated flood deposits typically contain 50% to 95% white and light to dark gray (GLEY 4/N-8/N) or altered reddish gray or weak red (10R 6/1, 10R 4/3) dacite, commonly with white (10YR 8/1) to pinkish white or pale yellow to very pale brown pumice (2.5Y 8/2; 10YR 7/4, 8/2-8/3) (up to 16 cm or 6.3 in.) that locally constitutes up to 50% of the clasts; also contain pumice lenses, cobble to boulder rip-up clasts of lacustrine or glaciolacustrine clay, and clasts of White Chuck vitric welded tuff. Deposits vary from massive, crudely graded, or weakly horizontally stratified to rarely well-stratified with plane or cross bedding (this study; Beget, 1981; J. D. Dragovich, Wash. Divn. of Geology and Earth Resources, unpub. data). Locally divided into:

Qvl_w — **Non-cohesive lahar (late Pleistocene)**—Cobbly to locally bouldery gravelly sand commonly with a trace of ash; compact; light reddish brown; dacite-rich; dacite clasts up to 55 cm (22 in.); pumice clasts up to 4 cm (1.5 in.) and commonly flow-banded. Matrix composed of crystal-vitric fine to coarse sand with hornblende, quartz, plagioclase, pumiceous ash, and pumice. Dacite composes 60% to 95% of the gravel and cobble component and is white and light to dark gray (GLEY 1 4/N-8/N, 2.5Y 8/1-8/2) and less commonly weak red (10R 4/3); dacite clasts are mostly angular and vesicular with flow banding in some clasts. Locally abundant brown to very pale brown and pink to white (10YR 8/2-8/4; 7.5YR 5/3, 8/4, 5YR 8/1) pumice concentrated near the top of the lahar. Rare gravel- to boulder-sized rip-up clasts of clay or clay with scattered gravel (probable dropstones) and rounded to subrounded clasts of granite, phyllite, and vein quartz. Mostly nonstratified with weak normal grading near the top; symmetrical coarse-tail grading. Commonly overlies recessional outwash. Thin reworked(?) ash beds at contact with outwash at a few localities. Deposit ~1.5 m (5 ft) to perhaps locally 20 m (70 ft) thick (cross section B–B′).

Pleistocene Glacial and Nonglacial Deposits

Glacial Deposits of the Fraser Glaciation

Deposits of the Vashon Stade and Everson Interstade of the Fraser Glaciation of Armstrong and others (1965) occur throughout the study area. Vashon Stade continental ice advanced up the Skagit, Sauk, and Stillaguamish River valleys about 15,500 to 15,000 yr B.P., blocking the major river valleys and forming temporary lakes in front of the advancing ice. Vashon ice covered the entire study area until about 14,000 yr B.P. The maximum extent of the Fraser continental ice lobe is mapped near the study area, directly east of Darrington (Tabor and others, in press). Deglaciation commenced about 13,500 yr B.P. and the map area was probably fully deglaciated by about 11,500 yr B.P. (Porter and Swanson, 1998; Dethier and others, 1995; Pessl and others, 1989). Ice occupation in the study area appears likely during deposition of at least part of the White Chuck assemblage (units Qvs_w and Qvl_w).

Everson Interstade

Qgo_e — **Recessional outwash (Pleistocene)**—Sand, sandy gravel, gravelly sand, and sandy cobbly gravel with some boulders; loose, braided river to locally deltaic deposits; clasts are subrounded and commonly polymictic with locally abundant granite and locally derived subangular phyllite and vein quartz; rare interlayered thin to laminated beds of sandy silt and silt. Locally contains rip-up clasts of glacial lake deposits. Non- to well-stratified; meter-thick, subhorizontal beds commonly crudely defined by variations in cobble, gravel, and sand content; pebble imbrication, scour, and local low-amplitude cross-bedding common. Typically poor in Glacier Peak dacite and (or) pumice (0–5%). However, some of the outwash sands and gravels south of the Stillaguamish River contain as much as 40% dacite and pumice probably derived mostly from the late-glacial White Chuck assemblage. Terraces composed of recessional outwash deposits probably formed as kame terraces. Locally divided into:

$Qgog_e$ — **Recessional outwash, gravel (Pleistocene)**—Sandy gravel, gravelly sand, and sandy cobbly gravel locally with boulders; loose; subangular to subrounded; mixed local and Canadian clast provenance with rare dacite clasts.

$Qgos_e$ — **Recessional outwash, sand (Pleistocene)**—Sand; loose; subangular to subrounded; locally rich in pumice, dacite, and crystals and thus may locally grade into the White Chuck assemblage.

$Qgod_e$ — **Deltaic outwash (Pleistocene)**—Sand, sandy gravel, and cobbly sandy gravel; loose; moderately to well-sorted; beds are commonly 5 m (16 ft) thick with planar foreset beds in sets ten(s) of meters high dipping 25 to 30 degrees toward the valley; locally overlain by cobbly gravel topset beds along a scoured contact; typically contains locally derived clasts of phyllite, vein-quartz, greenstone, and sandstone mixed with clasts of Canadian provenance.

Qgl_e — **Recessional glaciolacustrine deposits (Pleistocene)**—Silty clay, clay, silty sand, and sand with local dropstones; gray to light gray; well-sorted; loose, soft, or stiff; nonstratified to laminated with rhythmite beds typically 1 cm (0.4 in) thick resembling varves; contains decimeter-wide sand dikes in the Stillaguamish valley; probably formed in glacial lakes impounded by retreating glacial ice; locally interfingers with recessional outwash.

Vashon Stade

Qgt_{vi} — **Ice contact deposits (Pleistocene)**—Sandy gravel, gravelly sand, and bouldery cobbly gravel, locally with interlayered beds of silty sand or sand; poorly to well-sorted; loose; boulders to 1.3 m (4.3 ft); typically clast-supported; rare flow and (or) ablation tills with a sand to silt matrix; beds are typically a decimeter to several meters thick. Contains near-ice structures, including oversteepened foreset bedding, ice-shear folds, and kettles, and subhorizontal beds of fluvial outwash typical of unit Qgo_e. Clasts are of mixed Canadian (granite and orthogneiss locally >50%) and local (for example, greenschist) provenance; locally contains clasts of Glacier Peak dacite (up to 20%, typically 3–5%); dacite clasts are light to dark gray or pale red and up to 0.95 m (3 ft) wide; also locally contains lenses of pumice. Ice-contact deposits are richer in dacite and pumice than most recessional outwash; it is likely that some White Chuck assemblage detritus followed ice-marginal paths down the southern part of the Stillaguamish River during deglaciation (Dragovich and others, 2002b; J. D. Dragovich, Wash. Divn. of Geology and Earth Resources, unpub. data). Abundance of gravel- to boulder-sized rip-up clasts of glaciolacustrine clay suggest excavation of lake deposits by glacial-ice and (or) volcanic dam breakout mechanisms; ice-contact deposits are inferred to locally interfinger with glaciolacustrine deposits (unit Qgl_e).

Qgt_v — **Till (Pleistocene)**—Nonstratified, compact, matrix-supported mixture of clay, silt, sand, and gravel in various proportions with disseminated cobbles and boulders; typically mottled dark yellowish brown to brownish gray, grayish blue, or very dark gray; matrix consists of silty fine to coarse sand (± clay). Includes clasts of Canadian and local provenance; up to 90% of clasts are locally derived and include angular to subangular phyllite or greenstone and rare Glacier Peak dacite. Till unconformably overlies bedrock in elevated alpine settings and locally occurs in the low valley-bottom glacial terraces, thus mantling topography.

Qga_v — **Advance outwash (Pleistocene)**—Medium to coarse sand, pebbly sand, and sandy gravel with scattered lenses and layers of pebble-cobble gravel; locally contains fine silty sand, sandy silt, and clay interbeds; well-sorted; compact. Subhorizontal bedding or cross-stratification prominent; localized cut-and-fill structures and trough and ripple cross-beds. Mostly Canadian provenance, some locally derived clasts, and little or no Glacier Peak dacite. Interfingers with and conformably overlies unit Qgl_v as a result of glacial lake impoundment during ice advance up the Stillaguamish River valley; composite sections of advance outwash and glaciolacustrine deposits are up to 150 ft (46 m) thick. Primarily fluvial in origin; based on stratigraphic relations including subsurface stratigraphy, some advance outwash is inferred to be deltaic (cross sections A–A′, B–B′).

Qgl_v — **Advance glaciolacustrine deposits (Pleistocene)**—Clay, clayey silt, silt, silty clay, and silty fine sand with local dropstones; locally contains fine- to medium-grained sand lenses and beds; stiff; well-sorted; thinly bedded or laminated. Silts and clays are dark gray, blue gray, and gray, weathering to pale yellowish brown; 1 to 4 cm (0.4–1.6 in.) thick rhythmite bedding (varves?) common, normally graded from sand to silty clay. Soft-sediment and (or) ice-shear deformational features are common and include tilted and contorted bedding, overturned folds, and flame structures; overturned fold geometries are consistent with ice shear during ice advance up the major river valleys. Underlain by unit Qc_o and locally overlain by and interbedded with unit Qga_v (cross sections A–A′, B–B′).

Deposits of the Olympia Nonglacial Interval

Qc_o — **Deposits of the Olympia nonglacial interval (Pleistocene) (cross-sections only)**—Gravel, silty sand, silt, silty clay, and peat, locally with disseminated organic material; logs or wood fragments are common; typically compact, well-sorted, and very thinly to thickly bedded; represents fluvial and swamp deposits from the last nonglacial interval.

TERTIARY VOLCANIC, INTRUSIVE, AND SEDIMENTARY ROCKS

Volcanic and Intrusive Rocks

Ev — **Volcanic rocks (Eocene)**—Nonmarine basalt, andesite, and dacite with minor rhyolite, volcanic sandstone, crystal lithic tuff, and tuff breccia; mostly pale brown or brownish red or pale to dark green gray to dark gray; includes flows, dikes, and pyroclastic and volcaniclastic rocks; felsic tuffs are white, weathering to tan. Textures vary from aphyric to porphyritic with trachyitic textures locally conspicuous; abundant plagioclase and less common augite and (or) pigeonite phenocrysts. Flows commonly amygdaloidal; common alteration minerals include disseminated chlorite, calcite, limonite, quartz, prehnite, sulfides, and epidote. Middle to late Eocene and possibly earliest Oligocene age; probably unconformably overlies the Chuckanut Formation (Jones, 1959; Tabor and others, 1988, in press; Evans and Ristow, 1994; this study).

Eian — **Intrusive andesite (Eocene)**—Andesite dikes; porphyritic; light brown, dark green, or dark greenish gray; phenocrysts include quartz and plagioclase (albite to andesine), locally with hornblende and (or) augite; common alteration minerals include disseminated chlorite, quartz, zeolites, sulfides, and calcite. Although not directly dated, intrusive andesite is probably Eocene and possibly early Oligocene in age and may represent feeder bodies for unit Ev (Jones, 1959; this study).

Sedimentary Rocks of the Chuckanut Formation

The 1,700 to 2,250 m (5580–7380 ft) thick Coal Mountain unit of the Chuckanut Formation (Evans and Ristow, 1994) is early to early middle Eocene in age and is unconformably overlain by the ~1,700 m (5580 ft) thick Mount Higgins unit of the Chuckanut Formation (Evans and Ristow, 1994). The Mount Higgins unit is probably unconformably overlain by Eocene volcanic rocks (unit Ev) and is middle Eocene in age. (Also see Tabor, 1994.)

Ec_c — **Coal Mountain unit (Eocene)**—Feldspathic fluvial sandstone with lesser conglomerate, mudstone, siltstone, and coal; thick- to very thinly bedded; well-sorted; clasts are rounded to subrounded; sandstone is micaceous, medium- to coarse-grained, and plagioclase-rich, and contains about 10% metamorphic lithic (mostly phyllite) clasts; sandstone–shale ratio is about 3:1. Sandstones are light brownish gray to light gray, weathering to very pale yellow or brown. Trough cross-bedding, ripple lamination, or plane lamination common in the coarse-grained beds. Fine-grained beds contain laminated mudstone, ripples, flute casts, and plant fossils (Johnson, 1982, 1984a,b; Evans and Ristow, 1994; Tabor and others, in press; this study).

Ec_h — **Mount Higgins unit (Eocene)**—Feldspathic to lithofeldspathic fluvial sandstone, siltstone, and mudstone, with minor conglomerate, coal, and altered tuff (bentonite); sandstone–shale ratio is about 2:1. Cross-bedding, laminated mudstone, symmetrical ripple marks, mudcracks, leaf litter layers, sole marks, and paleosols locally observed. The Mount Higgins unit is differentiated from the Coal Mountain unit by increased amounts of polycrystalline quartz, chert, and sedimentary lithic fragments in sandstones (Johnson, 1982, 1984a,b; Evans and Ristow, 1994; Tabor and others, in press; this study).

MESOZOIC LOW-GRADE METAMORPHIC ROCKS (BLUESCHIST FACIES)

Thrust-faulting and nappe formation in the Northwest Cascades System occurred in the Cretaceous (~110–90 Ma) (see Brown, 1987). Where not complicated by younger high-angle Tertiary faulting, the Easton Metamorphic Suite of the Shuksan nappe structurally overlies the Haystack terrane along low-angle thrust faults.

Easton Metamorphic Suite of the Shuksan Nappe

The Easton Metamorphic Suite of Tabor and others (1994) includes the Darrington Phyllite, semischist of Mount Josephine, and the Shuksan Greenschist. These units are interlayered on mountain to outcrop scales and are interpreted to be oceanic crust (Shuksan Greenschist and part of the Darrington Phyllite) and submarine fan deposits (part of the Darrington Phyllite and the semischist of Mount Josephine). Semischist and phyllite are locally interlayered on a scale of millimeters to meters; these are interpreted as distal turbidite and basin-plain deposits. Shuksan Greenschist is mostly mid-oceanic-ridge metabasalt. Rocks of the Easton suite typically have a penetrative S1 (first-generation) foliation, with bedding transposed subparallel to S1 and abundant quartz segregation along S1. The Easton Metamorphic Suite is probably Jurassic (Armstrong and Misch, 1987; Brown and others, 1982; Brown, 1986, 1987; Gallagher and others, 1988; Tabor and others, 1994; Dragovich and others, 1998, 1999, 2000a).

Darrington Phyllite and (or) semischist of Mount Josephine (Jurassic)—Metasediments of the Shuksan nappe are divided into three map units on the basis of the percentage of interbedded phyllite and semischist:

Jph_d — 90–100% Darrington Phyllite (0–10% semischist of Mount Josephine)

Jph_{dj} — 50–90% Darrington Phyllite (10–50% semischist of Mount Josephine)

Jph_{jd} — 0–50% Darrington Phyllite (50–100% semischist of Mount Josephine)

Darrington Phyllite consists of sericite-graphite-albite-quartz phyllite to graphitic quartz phyllite (metashale or metasiltstone) with rare interbeds of micaceous quartzite (metachert) and albite schist; some phyllite is bluish black to black due to disseminated graphite (relict organic matter); silver-colored phyllites are muscovite rich; metamorphic minerals include chlorite, epidote, muscovite, lawsonite, and rare garnet; large albite porphyroblasts observed locally. Phyllites characteristically display two to locally three generations of folding. The second generation of folding (F2) is the most conspicuous and commonly has a subhorizontal fold axis oriented west-northwest or east-southeast.

Semischist of Mount Josephine consists of lithic-subquartzose semischistose sandstone or feldspathic metawacke; rare metaconglomerate; light green gray, green gray, medium gray, and light bluish gray. Semischist typically contains abundant stretched relict sand grains of polycrystalline and monocrystalline quartz, albitized plagioclase, and sparse lithic fragments; metamorphic minerals are similar to those of the Darrington Phyllite (Jones, 1959; Morrison, 1977; Tabor and others, 1988, 1994, in press; Dragovich and others, 1998, 1999, 2000a).

Jsh_s — **Shuksan Greenschist (Jurassic)**—Mostly well-recrystallized metabasalt; strongly S1 foliated; locally includes iron- and manganese-rich quartzite (metachert) and graphitic phyllite interlayers; greenschist locally contains epidote segregations or primary layers and is mostly shades of greenish gray and weathers to light olive gray; blueschist is bluish gray to bluish green. Greenschist commonly layered on a centimeter scale; S1 foliation and layering are commonly folded on an outcrop scale. Relict igneous minerals locally include saussuritized and albitized plagioclase laths, actinolized hornblende, and rare clinopyroxene. Metamorphic minerals include albite, actinolite, epidote, and chlorite with lesser lawsonite, Mg-pumpellyite, muscovite, spessartine, and calcite. In rocks of the appropriate iron composition and oxidation state, Na-amphibole (for example, crossite) replaces actinolite as the primary metamorphic amphibole to form blueschist instead of greenschist; greenschist and blueschist are locally interleaved at outcrop scale (Haugerud and others, 1981; Brown, 1986; Tabor and others, 1988, in press; Morrison, 1977; this study).

Helena–Haystack Mélange or Haystack Terrane

The Haystack terrane of Whetten and others (1980, 1988) or the Helena–Haystack mélange of Tabor (1994) is a serpentinite-matrix mélange. U-Pb zircon ages obtained from meta-igneous rocks indicate a Jurassic age of about 160 to 170 Ma (Whetten and others, 1980, 1988; Dragovich and others, 1998, 1999, 2000a; Tabor and others, 1988, in press; this study).

Jmv_h — **Greenstone (Jurassic)**—Metabasalt to metadacite; rare meta-rhyolite; locally contains amygdules and pillows; greenish gray, light olive gray, or grayish green; commonly nonfoliated; locally contains strong spaced cleavage. Relict augite and saussuritized plagioclase common; relict hornblende rare. Metamorphic minerals include albite, acicular actinolite, Fe- and Mg-pumpellyite, prehnite, lawsonite, stilpnomelane, aragonite, and calcite. Commonly hydrothermally altered; regional geochemistry suggests a mid-oceanic-ridge to oceanic-island-arc origin (Tabor, 1994; Tabor and others, in press; Dragovich and others, 1998, 1999, 2000a). Commonly weathers out of serpentinite mélange matrix as steep resistant hillocks.

$Jigb_h$ — **Metagabbro (Jurassic)**—Medium-grained to rarely coarse-grained and uralitic; light greenish gray, olive gray, and dark greenish gray; nonfoliated to locally protomylonitic. Metamorphic minerals include acicular actinolite, epidote, chlorite, and pumpellyite with minor white mica, calcite, and (or) aragonite. Recrystallization is partial and static. Dominant relict igneous minerals include saussuritized and albitized plagioclase, augite and rare brown hornblende; ophitic or subophitic relict igneous textures common. Commonly weathers out of serpentinite mélange matrix as steep resistant hillocks.

Ju_h — **Ultramafite (Jurassic)**—Serpentinite and minor silica-carbonate rock and rare peridotite or pyroxenite; ultramafite forms mélange matrix; serpentinite is dark green gray to greenish black and weathers to pale green or distinctive dark yellowish orange; magnesite and silica-carbonate veins and bodies are very pale orange. Relict pyroxene and (or) olivine locally observed. Cretaceous to Tertiary faulting locally imbricate the ultramafic rocks with rocks of the Easton Metamorphic Suite and (or) Chuckanut Formation (Tabor and others, 1988; Jones, 1959; this study).

LOW-GRADE MESOZOIC METAMORPHIC ROCKS OF THE EASTERN MÉLANGE BELT

The rocks of the Eastern mélange belt (EMB) of Tabor and others (in press) occur south of the regionally important Darrington–Devils Mountain fault zone, which traverses the study area. Tabor (1994) suggested that the Eastern mélange belt may have been thrust over rocks of the Northwest Cascades System. Rocks of the Eastern mélange belt are metamorphosed to the prehnite-pumpellyite or perhaps the blueschist facies (Tabor and others, in press).

Jar_e — **Meta-argillite (Jurassic)**—Black; locally foliate with carbonate concretions and minor fine-grained metasandstone interbeds; locally cut by deformed and brecciated metadacite dikes. Radiolarians from a concretion directly south of study area are Middle to Late Jurassic (Tabor and others, in press).

$J\bar{T}mt_e$ — **Greenstone (Jurassic–Triassic)**—Metamorphosed pyroxene andesite, basaltic andesite, and dacite with minor diabase and gabbro; locally contains thin metasedimentary interbeds; dark gray or dusky green to greenish black. Locally displays amygdaloidal flow tops, breccia, and tuff (Tabor and others, 1988, in press; this study).

$\bar{T}mb_e$ — **Marble (Triassic)**—Mostly coarsely crystalline gray to white marble. A limestone pod directly south of the study area produced Late Triassic conodonts (Tabor and others, in press).

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Geologic Map of the Fortson 7.5-minute Quadrangle, Skagit and Snohomish Counties, Washington

by
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